Electronic Parts and Spacecraft Reliability: Considerations for Planetary Protection

Karla B. Clark

Jet Propulsion Laboratory – California Institute of Technology

Presentation to

The Committee on Planetary Protection Standards for Icy Bodies in the Outer Solar System

Agenda

- Mission Classification
- Design for Planetary Protection
  - EEE Parts
  - Materials
  - Sensors
  - Circuit Cards
  - Boxes
- Spacecraft Integration
- Cost Considerations
- Summary

Mission Classes

- NPR 7120.5D*: Category 1, 2 or 3

Category 1	LCC** > $1B, or use of nuclear power source, or human space
Category 2	$250M </= LCC</= $1B, or High Priority with LCC/= $250M
Category 3	LCC </= $250M and medium or low priority

- NPR 8705.4*: Risk Classification A, B, C, D
  - see backup for details

Class A	low risk, high priority, very high to high complexity, long life
Class B	low risk, high priority, high to medium complexity, medium life
Class C	medium risk, medium priority, medium to low complexity, short life
Class D	high risk, low priority, low complexity, short life

*See backup for governing document references **LCC = Life Cycle Cost

Design for Planetary Protection

- If part of the design process, ease of meeting planetary protection requirements can be increased
  - Aim for tolerance of process (e.g., heat at 110°C or more)
  - Use Class S/MIL specification parts
  - Allow margin –for gradients and for repeat (rework/hierarchical) processing
  - Material selection choices (compatibility with cleaners and temperatures)
    - (Metallic vs. organic)
    - Dimensional stability/Coefficient Thermal Expansion mismatch issues
    - Effects on adhesives and lubricants
  - Consider assembly options: e.g. boards in boxes, accessibility for rework, HEPA filter/biobarrier incorporation
  - Spacecraft assembly processing plans

Hardware Design

- Choose materials carefully to withstand chosen sterilization process(es)
  - Paints and other coatings
    - Change color
    - Lose thermal properties
    - Flake
  - Lubricants
    - Can melt and run
    - May lose lubricating ability
    - Become gummy
  - Adhesives, bonding agents
    - Softening of thermoplastics
  - Insulating materials
    - Melt
    - Flake
    - Brittle
- Choose materials that can be cleaned
- Choose materials that can be biosampled

Hardware Design

- Many batteries have issues being exposed to heat above 50C
- Sensors require very special attention
- Look out for surprises
  - Solder that melts at lower temperatures
  - Complex hardware from multiple contractors where one piece cannot meet requirement
  - Bonding agents, staking compounds
  - Thermal expansion mismatches (can effect calibrations and alignments if not properly accounted for)
  - Magnetics – property changes
- Unplanned late additions to the flight system
  - Be rigorous

EEE Parts

***EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification and Derating*, NASA/TP—2003--212242, NASA-Goddard SFC, April 2008, Incorporating Addendum 1**

- Scope
  - Establishes baseline criteria for selection, screening, qualification and derating of EEE Parts for space flight projects based upon mission needs and classification levels.

- Key Definitions

  Screening
  - Intended to remove nonconforming parts (parts with random defects that are likely to result in early failures, known as infant mortality) from an otherwise acceptable lot and thus increase confidence in the reliability of the parts selected for use.
    - Electrical test (Generally -55, 25, +125C)
    - Burn-in
    - Temp Cycling, etc.

  Qualification
  - Consists of mechanical, electrical, and environmental inspections, and is intended to verify that materials, design, performance, and long-term reliability of the part are consistent with the specification and intended application, and to assure that manufacturer processes are consistent from lot to lot.
    - Group A Electrical tests (Static, Dynamic, Switching, Functional over temperature)
    - Group C Environmental related (Temp Cycling, Life Test, etc.)

Parts Classification

- GSFC-INST-002: Parts level 1,2,3
  - Level 1 – *highest reliability and lowest level of risk*
  - *Level 2 - low to moderate risk*
  - *Level 3 - high risk or unknown risk*
- Basic mapping of requirements:

Mission Class

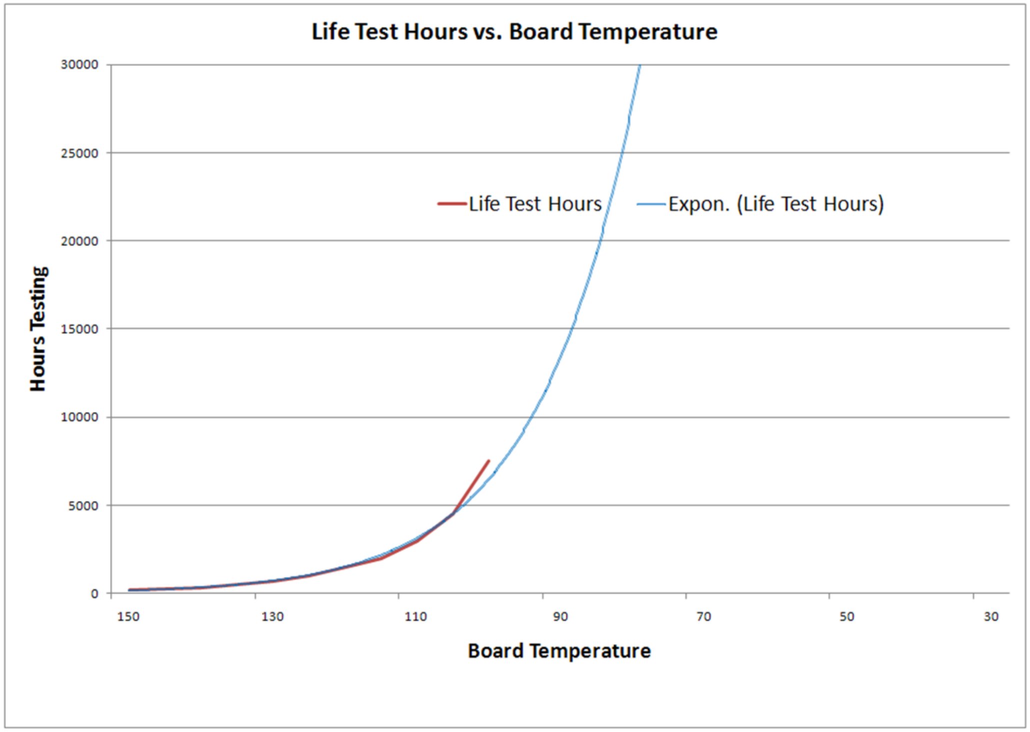
Part Class	Class A	Class B	Class C	Class D
Level 1	X			
Level 2		X		
Level 3			X	

General EEE Parts Approaches

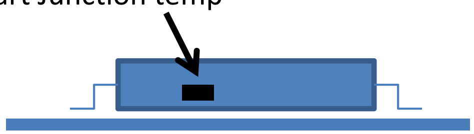
- Level 1
  - Hybrids : Class K
  - Microcircuits : Class V/S
  - Discrete Semiconductors : JANS
  - Passives : FRL S or R
  - Maximum recommended junction temperature 175C
- Level 2
  - Level 1 parts
  - Hybrids : Class H
  - Microcircuits : Class Q/B
  - Discrete Semiconductors : JANTXV/TX
  - Passives : FRL P or higher
  - Maximum recommended junction temperature 200C

EEE Parts Testing

- Burn-in and life testing is performed with parts operating
- DHMR can used done without parts operating
- Hours at DHMR temperatures will not effect lifetime of parts except for very long life operational missions



Part Junction temp



Board and surrounding temp

Typical maximum temperature rises for parts

	Operating	Non-Operating
Board Temperature	125C	125C
Maximum Junction Temperature	150C	125C
Maximum Temperature Rise	25C	0C

Testing Standards

- MIL- STD-883 Test Method Standard, Microcircuits
  - Burn-in
    - Class S/H/K minimum 125C for 240 hours
    - Class B minimum 100C for 352 hours or 125C for 160 hours
  - Life test
    - Class S/H/K minimum 125C for 1000 hours
    - Class B minimum 100C for 7500 hours or less hours at higher temperatures
- MIL- STD-750 Test Methods for Semiconductor Devices
  - Burn-in
    - JANS minimum 125C for 240 hours
    - JANTXV minimum 125C for 160 hours
  - Life test
    - JAN Product 125C for 1000 hours
- MIL-STD-202 Test Method Standard, Electronic and Electrical Component Parts
  - Burn-in (Part dependent)
    - Typically 125C for minimum of 100 hours
    - Some Mil-Prf-39022 metallized plastic film capacitors are limited to 85C
  - Life test (Part dependent)
    - Typically 125C for minimum of 1000 hours

Materials

- Outgassing : Processing generally consists of a bakeout at 125C and 10-6 Torr for 24 hours (ASTM E-595-90).
- Material service temperature limit
  - Metals:
    - Most can withstand DHMR with no problem
    - Formed or shaped thin pieces may assume unwanted new positions during heating
    - Mixed metal configurations may lead to unidentified intermetallic growth
  - But make sure there are no Coefficient of Thermal Expansion issues when heating dissimilar materials with close tolerances

Cables, Contacts and Connectors

- Outgassing: Processing generally consists of a bakeout at 125C and 10-6 Torr for 24 hours.
- Temperature cycling of Connectors: 5 cycles -55C to 125C

Fiber Optics, Passives
(Fiber, Cables, Connectors, and Assemblies)

- Acrylates between 85C up to 200C
- Polyimides >/= 125C
- Outgassing: Processing generally consists of a bakeout at 125C and 10-6 Torr for 24 hours

Material	Temperature Limits
Tefzel 200	Melting Point: 270 C Operating Range: -70 C to 200 C
Teflon, PFA	Melting Point: 300 C
Tefzel (ETFE)	Operating Range: -70 C to 200 C
Kevlar 49	Max Operating: 177 C
Teflon PTFE	Melting Point 343 C Operating Range: -80 C to 260 C
Teflon FEP	Melting Point: 285 C Operating Range: -200 C to 200 C
Gore-Tex Expanded PTFE	Melting Point: 327 C Operating Range: -200 C to 260 C
Kynar (PVDF)	Melting Point: 347 F Max Operating: 135 C
~~Hytrel~~	~~Operating Range: 50 C~~

Sensors

- Issues are very sensor-type dependent
  - Basic materials may be fine
  - Bonding agents and films may be issues
- Work with manufacturer to see what processes are used in fabrication
  - Many times high temperatures are used in fabrication process
- Specialized process may be required to meet DHMR requirements

Circuit Cards

- Circuit cards are used for many applications of life testing and Burn-in
- They must survive same temperatures as the parts
- Options for materials exist that can be heated for extended times above 125C

Resin System	Tg (°C)
Polyimide	200–250
FR-4 (difunctional)	125
FR-4 (multifunctional)	170

The Tg is that temperature at which the resin system making up the PWB loses its rigidity and becomes rubber-like; its electrical and mechanical properties are also seriously degraded. Resin systems with higher Tgs are favored.

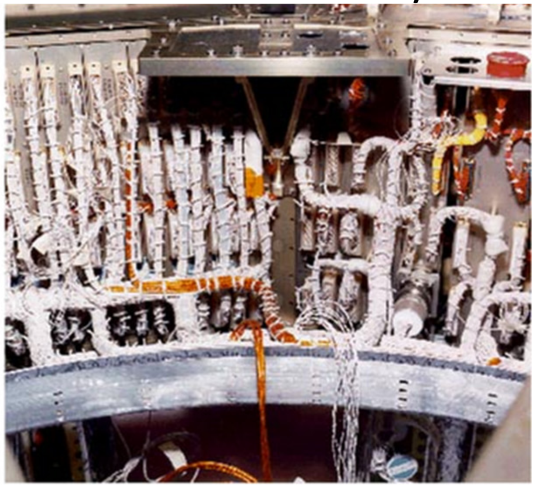
Boxes

- Box material typically metal
- Can be heated above 125C
- Early incorporation of design features facilitates elevated temperature heating and minimizes/eliminates recontamination
  - Covering all openings
  - HEPA filters
  - Internal "bagging"

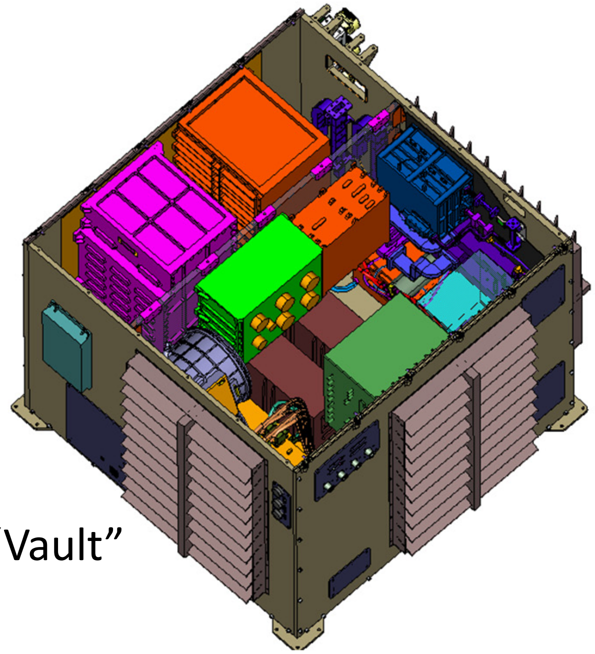
Configuration Issues

- Need to assess how boxes are assembled on spacecraft
  - Cassini "bay" structure incorporates boards directly into spacecraft structure
  - Individual boxes or "Chassis" can be delivered "Clean" and maintained "clean" if designed correctly
  - Juno vault approach accommodates finished boxes but limits access after assembly

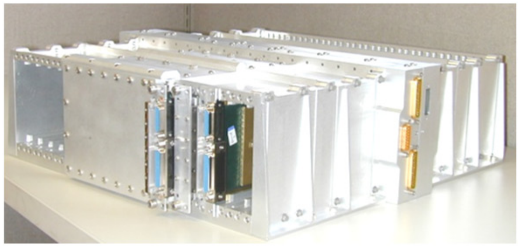
Cassini Power "Bay"



Custom "Chassis"



Juno "Vault"



Standard 3U "Chassis"

Spacecraft Assembly

- Box/Spacecraft mechanical design influences ease of assembly and cleaning especially considering planetary protection issues
  – Minimize crevices, sharp corners
  – Emphasize smooth surfaces
  – Surface finishes (e.g. anodizing vs. coatings, different coating choices)
  – Access to hardware for rework

Contamination Prevention

- People are the biggest contamination generators
- Keeping the hardware clean minimizes large scale recleaning/ decontamination activities
  - Clean everything before it enters the cleanroom
  - Use proper clean room techniques and garmenting
  - Keep your tools clean
- Don't set them on the floor
- Clean hardware should be covered as much as possible
  - Ranges from simple draping with clean antistatic material to one of a kind fitted sealable bags during assembly and test operations
- Consider using flight biobarriers
  - Sterilize instrument or other hardware inside of biobarrier

Sampling

- Wipe Samples
  - Sterile polyester cleanroom cloth with distilled water or PP rinse solution
- Swab Samples
  - Cotton
  - Polyester
  - Distilled water
- Supplemental Assays
  - Rapid techniques used to determine presence of microbial contamination to quickly assess if cleaning or other processing is needed prior to NASA Standard assay
    - Total Adenosine Triphosphate (t-ATP)
    - Limulus Amebocyte Lysate (LAL)
- Many samples are taken over the life of a mission
- Goal is to sample 10 % of the surface area to get statistically significant results
- Mars Polar Lander had more than 1200 samples
- MER (2 Rovers) had a total of 3766 swab and 529 wipe samples

Data Tracking

- Planetary Protection Equipment List
  - Organic Materials Inventory/samples
  - Biological and classical contamination control as actually practiced
  - Hardware treatment history
- Data records of any microbial reduction
  - Currently 10, 3 inch notebooks for MSL (and growing!)
  - Assay results
- Data Base and Statistical treatment
  - Hardware movement after assays or microbial reduction process
  - Recontamination threat mitigation as actually practiced
  - PP required plans, documents and reviews from
- Categorization Request to End of Mission Report

Cost Considerations – New Designs

- If designing from scratch *AND* use Level 1 EEE Parts and Materials, cost impact can be minimized
  - Typically this is already a more costly approach
  - Engage PP Subject Matter Experts early
  - Design with Class S or Class B parts
  - New packaging design
  - Sensors would need special attention for design, fabrication and assembly
  - Design in robustness to performance variations
- High precision requirements require special attention
- Consider calibration and alignment robustness
- Considerably variable based on level of Bioburden reduction needed and performance requirements
  - Rough order estimate 5-15% increase of an assembly/box cost

Cost Considerations – Existing Design

- Reworking existing design may have larger impact depending on the amount of rework required
  - Potential loss of heritage
    - Redo packaging
    - Redo analyses
    - Performance changes
  - Redesign to add robustness to performance variations
  - Cost increase for more expensive parts and materials
    - May need to redesign with Class B or Class S parts
  - Likely require additional testing
    - Loss of inheritance
    - New packaging
    - Consider calibration and alignment robustness
- Most difficult to estimate is effects on sensors
  - Likely will require new build with modified fabrication process
- High precision requirements require special attention
- Considerably variable based on level of Bioburden reduction needed and current design accommodations
  - Rough order estimate 5-25% increase of an assembly/box cost

Summary

- If considered from the beginning of design, its easier to incorporate approaches to meet planetary protection requirements
- Parts, materials and approaches are available to meet sterilization requirements
- Cost impact is highly dependent on
  - Level of PP requirements imposed
  - Design
    - New or existing
    - Parts classification
    - Number of sensors
    - Calibration/alignment requirements

Governing Documents

- NPR 7120.5D – NASA Space Flight Program and Project Management Requirements

- NPR 8705.4 – Risk Classification of NASA Payloads

NPR Risk Classification Definitions

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission	Long, >5years	Medium, 2-5 years	Short, <2 years	Short < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.	Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted.	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.
Examples	HST, Cassini, JIMO, JWST	MER, MRO, Discovery payloads, ISS Facility Class Payloads, Attached ISS payloads	ESSP, Explorer Payloads, MIDEX, ISS complex subrack payloads	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX

NOTES:
1. Mission impact; i.e., loss of function effect on other payloads or ISS operations may also be a characterization factor. For example, loss of the function of freezers and centrifuges may impact other payloads and increase the overall level of risk.
2. The safety risk to crew inherent in the operation of a human-crewed vehicle may be a factor in payload classification determinations. Class C and D payloads that have a medium or high risk of not achieving mission success may be considered unsuitable for launch on a crewed vehicle, unless they are secondary payloads making use of available launch capacity that would otherwise go unused.
3. Other situation-dependent payload classification considerations may include human-rating environment, logistics support, and interoperability interfaces.